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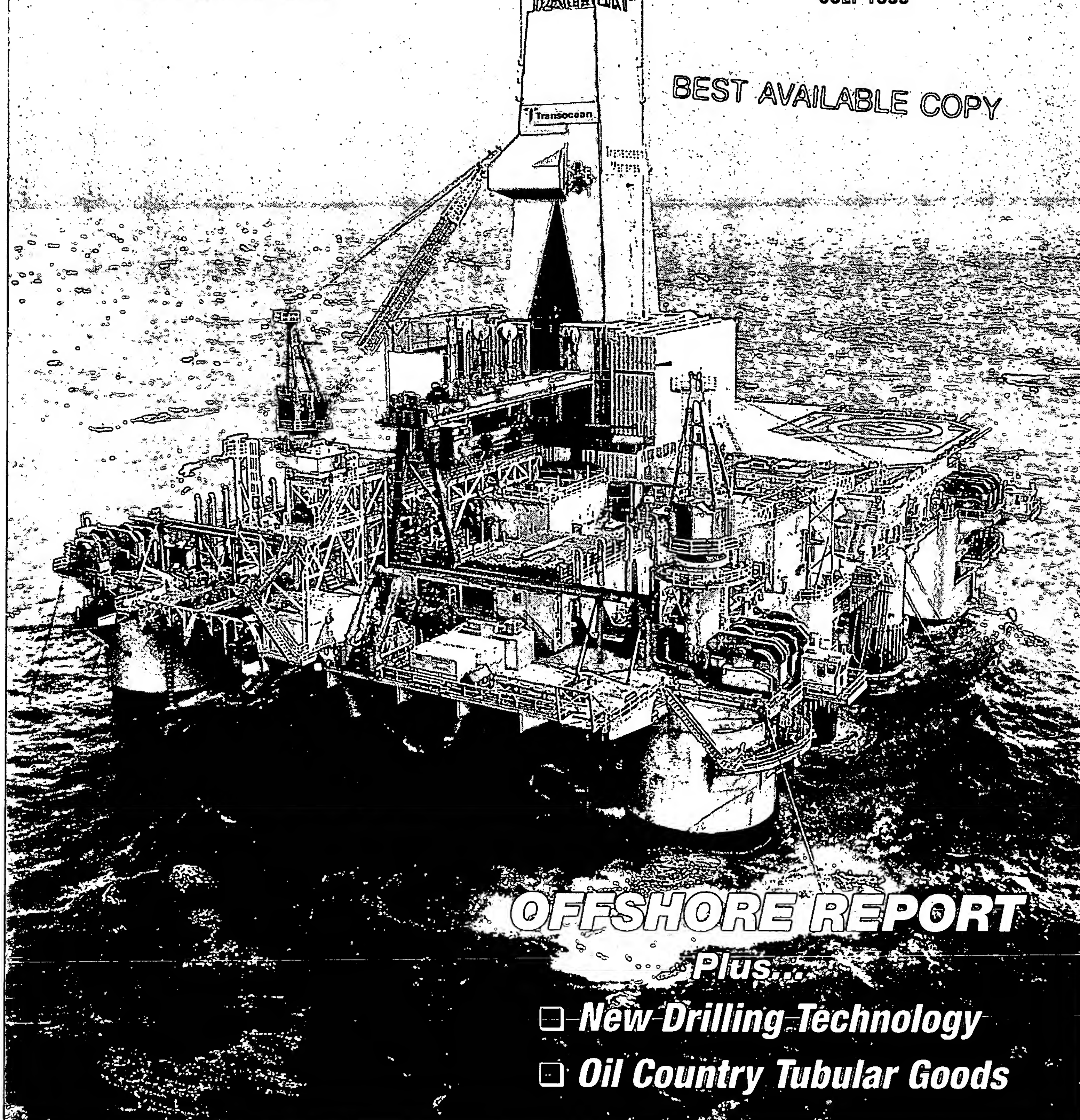

OFFSHORE REPORT

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How in situ expansion affects casing and tubing properties

Technique for expanding pipe downhole produces changes in mechanical properties and resistance to sulfide stress cracking that are somewhat counter-intuitive

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Interesting results are emerging from the ongoing research of a novel advancement—expandable tubular technology. Studies on the effects of expansion on the mechanical properties of post-expansion casing, the resistance of expanded casing to sulfide stress cracking and Hoop (tangential) stress resilience during expansion have demonstrated the viability of the process for field applications. This article presents results of some of the lab tests conducted to determine these effects.

This advancement in well completion technology and repair can improve the economics of well completions, make completions in difficult formations possible and salvage damaged completions through in situ well repair (for example, by cladding across damaged casing intervals). The process involves pushing a mandrel and lubricated cone assembly through the inside of expandable casing of smaller ID than that of the cone and expanding the tubular product downhole, Fig. 1.

Fig. 1. A finite element model of Hoop (tangential) stress distribution is shown next to an oil country tubular specimen under 20% expansion.

Selection of the proper materials for this assembly is crucial. The working piece—the cone—is subjected to high interfacial stresses as it expands the pipe. The shape of the cone and lubrication of the cone interface with the tubular product also are critical to successful performance. Materials for the components of the expansion assembly are chosen for sufficient strength, ductility, impact toughness and resistance to galling, wear and environmental cracking.

Table 1. Chemical composition (wt %) of expandable steels studied

Element	Grade K-55	Grade L-80
C	0.36	0.23–0.27
Cr	0.07	≤0.02
Ni	0.01	≤0.02
Mo	0.13	≤0.01
Mn	1.35	0.93–1.34
Si	0.27	0.22–0.27
P	0.014	0.010–0.015
S	0.004	0.003
Ti	0.001	0.001–0.010
Nb	<0.005	<0.005
Cu	0.01	<0.02
V	0.001	≤0.048
Al	0.028	0.044–0.048

Performance of standard grades of steel tubulars subjected to permanent expansion (up to 20%) was previously unknown. Initial lab experiments included flaring tests (which are much more meaningful than tensile tests) for determining the suitability of various *API 5CT* grades for expansion. Seam-welded products were chosen for the initial expansion studies because their wall thicknesses are more easily controlled. Table 1 shows chemical compositions of the K-55 and L-80 materials studied.

MECHANICAL PROPERTY TESTING

Knowledge of post-expansion mechanical properties is required for accurate service rating of the tubular product under evaluation. Post-expansion strength, ductility, impact toughness, collapse and burst have been studied for selected pipe sizes and compared to the same values for the pipe as received. All expansions discussed in this article were conducted at room temperature, but results of expansions at higher temperatures (up to 350°F) are similar in the limited set of materials studied to date. Further testing will be conducted at downhole temperatures.

Results of the mechanical-property tests for 5½-in., 17 ppf, Grade L-80 casing are summarized in Table 2. The data show that the expansion process does indeed affect the mechanical properties of the material. Ultimate tensile strength tends to increase, and the percentage of elongation tends to decrease, with expansion. These are the natural results of cold working the metal. Tests have shown that experimental difficulties associated with residual stresses in expanded tubulars can cause a high degree of variability in yield-strength test data. Hardness and tensile properties of the tested L-80 cas-

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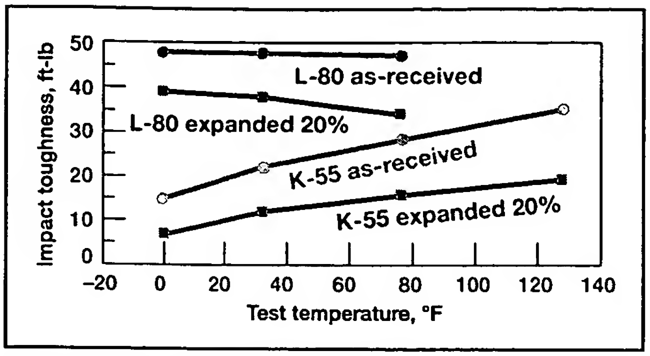

Fig. 2. Charpy impact toughness versus temperature for as-received and expanded tubular goods.

Table 2. Mechanical properties of Grade L-80 casing

Property	*API Spec 5CT* Grade L-80 Type 1 required	L-80 No expansion	L-80 20% expansion
Hardness, HB	241 max	200–205	217
Yield strength at 0.5% total extension, ksi	80 min	82.3	82.4
Ultimate tensile strength, ksi	95 min	96.9	104.8
Elongation, %	14 min[1]	27.1	19.4

[1]Per *API Spec 5CT* elongation formula

Table 3. Mechanical properties of Grade K-55 casing

Property	*API Spec 5CT* Grade K-55 required	K-55 No expansion	K-55 20% expansion
Yield strength at 0.5% total extension, ksi	55–80	70.2	79.4
Ultimate tensile strength, ksi	95 min	110.5	116.0
Elongation, %	9.5 min[1]	26	22

[1]Per *API Spec 5CT* elongation formula

ing changed after expansion; however, the casing still met *API Spec 5CT* requirements after 20% expansion. Similar results were obtained with Grade K-55, as shown by data in Table 3.

Test results also show that expansion changes the Charpy impact toughness of the expandable-tubular material. However, impact toughness at 32°F, and higher, is still acceptable, with 100% shear fracture in all cases studied except for that of the K-55 casing. Fig. 2 depicts these values graphically.

Expansion decreases the collapse rating of tubular goods, probably a result of the Bauschinger effect. The Bauschinger phenomenon occurs when plastic flow in one direction (expansion) lowers the applied stress at which plastic flow begins in the reverse direction (collapse). The test data for Grade L-80 indicate that, if the pre- and post-expansion dimensions are the same, collapse resistance should decrease by about 30% as a direct result of the expansion process. Collapse test data on 5½-in., 17 ppf, Grade L-80 pipe show that post-expansion collapse resistance was near or slightly below the minimum required by *API Bulletin 5C3*. Fortunately, studies have also shown that a significant portion of the material's initial collapse resistance can be recovered in situ through a special process under development. For example, application of this process to 20% expanded L-80 casing resulted in a 48% increase in post-expansion collapse resistance. Research continues so as to better understand this effect.

The expansion process appears to have no detrimental effect on burst strength. Burst pressure of expanded L-80 casing meets or exceeds general formulae expectations, and the fracture surface of all samples tested has shown ductile fracture behavior.

ENVIRONMENTAL CRACKING STUDY

Four-point bent-beam specimens machined from as-received, 10% expanded and 20% expanded L-80 casing were stressed to 100% of their measured yield strength and exposed to NACE TM0177 solution. This room-temperature test has a cover gas of 15 psi H_2S over an aqueous solution of five weight percent (wt%) NaCl, acidified to a pH of 2.8. The test evaluates a material's resistance to sulfide stress cracking. None of the specimens cracked during the 30-day exposure.

CONCLUSIONS

Permanent downhole expansion of casing and tubing in oil and gas wells offers new, economical solutions for well completions and remediations. Investigations to date show that the expansion process alters the mechanical properties of expandable tubular goods. Studies of expansion are in progress and so far validate the expected value of the technology. This article has focused on the effects of expansion on the properties of *API 5CT* Grades K-55 and L-80; however, Grades N-80, S-95 and P-110 also are viable candidates for expansion. **wo**

THE AUTHORS

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